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TRANSFORMING VETERINARY PRACTICE WITH ARTIFICIAL INTELLIGENCE (AI): A COMPREHENSIVE REVIEW OF APPLICATIONS FOR VETERINARY PRACTITIONERS

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ABSTRACT

Artificial Intelligence (AI) quickly evolves veterinary practice by enhancing diagnostic accuracy, treatment outcomes, workflow, and operational efficiency. Even though the benefits of AI integration in veterinary practice are well appreciated worldwide, the lack of awareness of the available AI applications in major domains of veterinary care is identified as a primary gap in the acceptance of these technologies by many veterinary practitioners. There are many available machine learning (ML) applications across various fields of veterinary care. These include applications that improve the accuracy of diagnostics, optimize operational efficiency, enhance workflow in practice settings, improve production animal health, sports medicine, wildlife and exotic animal health, and AI applications to augment one health implementation. Despite the advantages, these applications pose major limitations, including available data quality, ethical concerns, and challenges in accepting and integrating available AI tools in regular veterinary practice. This review article is intended to provide a snapshot of available applications for AI integration in veterinary practice with insights into the challenges and limitations. By exploring the available literature on the subject, the article seeks to augment the knowledge of the veterinary practitioner of how AI can be harnessed to their daily needs and ultimately enhance the productivity, improved animal health, and quality of life (QOL) of animals with due consideration to the challenges and limitations.

Keywords: Artificial Intelligence, Machine Learning, Veterinary Diagnostics, Treatment Optimization, One Health, Wildlife Health, Sports Medicine, Operational Efficiency

INTRODUCTION

Over the past two decades, the practice of veterinary medicine has experienced a paradigm shift through transformative approaches with artificial intelligence. By exploiting the vast set of datasets to generate advanced algorithms, the technology of artificial intelligence helps predict potential health risks in veterinary patients, thus improving productivity in food animals and contributing to the public health domain besides enabling proactive interventions (Basran and Appleby, 2022). Diverse patient profiles of companion, food animal, avian, wildlife, and exotic medicine make veterinary medicine unique from human medicine (Bellamy, 2023). AI-driven tools can supplement veterinarians in a multitude of services, including diagnostics, designing treatment protocols, analysing prognostics for treatment recommendations, and effective client communication. Despite the advancement of the application of AI in human medicine, high implementation costs and a lack of awareness of the available innovations are the major resistance experienced by veterinary practitioners. While customization and cross-functional learning with human medicine counterparts present significant challenges, many technological companies are actively promoting existing human medicine applications to tailor them for veterinary patients (Lustgarten *et al*., 2020). By staying abreast of the myriad of available opportunities that AI offers, veterinarians can enhance workflow and efficiency in their practice setup. This review article is intended to give a comprehensive understanding of the available platforms that are already available for veterinary practitioners. AI could leverage a borderless reservoir of veterinary data in the future, provided veterinarians worldwide accept AI interventions and take it as a common responsibility to develop and share the database for a better tomorrow.

Machine learning (ML) in veterinary medicine

Machine Learning (ML) is a part of Artificial intelligence that allows computers to explore the available datasets and self-learn with minimal program languages. The algorithms in ML help to process data to help with a multitude of services including diagnosis, treatment, and monitoring (Ding *et al*., 2023). The major subfields of machine learning are Computer Vision (CV) which focuses visual information on interpretation, Natural Language Processing (NLP) that deals with human language understanding and processing, and predictive analytics (Sahu *et al*., 2023). In general, ML provides the fundamental structure that makes it possible for different AI technologies to operate and advance via data-driven learning.

The four components of ML are supervised, unsupervised, semi-supervised, and reinforcement learning. Supervised learning uses classification and regression algorithms for mapping input data to output data by pre-defined commands; unsupervised algorithms work on large unlabelled datasets, which often do not need human intervention (El Hechi *et al*., 2021; Cunningham *et al*., 2008). The hybrid form of semi-supervised learning combines limited labelled data with a huge volume of unlabelled data, resulting in model accuracy and generalization (Duarte and Berton, 2023). Reinforcement learning is an environment-driven approach that automatically evaluates behaviour in a specific environment to improve efficiency (Sahu *et al*., 2023).The expanded overview of applications in AI in various fields in the practice of veterinary medicine is described below.

AI Applications in Veterinary Diagnostics

Specific AI applications in veterinary medicine are revolutionizing diagnostics in veterinary practice by enhancing accuracy and improving efficiency. One common area is AI augmented interpretation of diagnostic data and lab results which improves the clinical decision-making process (Fadan *et al*., 2019). Remotely available data such as histopathology and radiology images can be interpreted by telemedicine driven by artificial intelligence. (Mun *et al*., 2021; Steimetz *et al*., 2024). AI is instrumental in fostering informed clinical decision-making with the available data in blood diagnostics. An example of this is the AI application – 'Cortex' to analyse test results from other platforms like "IDEXX" and "VetConnectPlus". These algorithms developed from large datasets of radiographic images, can highlight abnormalities and help veterinary practitioners to make more accurate and faster diagnoses (Solomon *et al*., 2023). A company called "PetDx" has developed a test program "Onco K9" which is the application of ML for DNA analysis from canine blood samples. This kit detects cancer in dogs by identifying tumor-specific genetic markers, enabling veterinarians to arrive at accurate diagnoses (May, 2023). Another program "Companion Animal Health" uses predictive analytics in disease outbreak forecasts, augmenting effective preventive health care (Almazan *et al.,* 2020). A table summarizing various AI-driven applications in veterinary diagnostics is given below.

Table -1 AI driven applications in veterinary diagnostics

Product	Website	Country of Origin	Year	Description
IDEXX Vet Connect PLUS	www.idexx.com	USA	2017	Cloud-based platform utilizing AI to assist in interpreting diagnostic data and lab results.
VetCT	www.vetct.com	UK	2012	Telemedicine and remote diagnostics, including AI-driven image analysis for radiology and pathology.
PetPace	www.petpace.com	USA	2016	Smart collar monitoring vital signs and behaviour in real-time, using AI for early health issue detection.
Cortex	www.cortex.ai	Australia	2021	AI-driven software for analysing blood test results, aiding in informed diagnostic decisions.
SignalPET	www.signalpet.com	USA	2018	AI platform for analysing veterinary imaging, providing automated reports, and highlighting concerns.
PetInsight	www.petinsight.com	USA	2020	AI tool for analysing pet behaviour through video feeds, assisting in diagnosing behavioural issues.
Vetscan Imagyst	www.imagyst.com	USA	2021	AI-powered platform for rapid diagnostic imaging and pathology, streamlining the diagnostic process.
OncoK9	petdx.com	USA	2019	Cancer detection via genomic analysis
Vetology	vetology.com	USA	2018	Radiographic image analysis
PetDx	petdx.com	USA	2020	Genomic testing for pets
Vet AI	vet-ai.com	UK	2019	AI-powered diagnostics

AI-driven treatment optimization and operational efficiency

By analysing large volumes of patient data, machine learning applications can streamline clinical workflows in veterinary practice (Lyon *et al.,* 2021). Precise treatment recommendations are generated from a large volume of patient data sets comprising clinical history, laboratory and imaging data and client communication data (Fadan *et al*., 2019). Routine tasks in a veterinary clinical practise like appointment scheduling, inventory management, and data entry, are refined by AI-driven solutions, which eventually enhance operational efficiency by automating, allowing veterinary practices to focus more on patient care (Blasiak *et al.,* 2020). The algorithms generated by machine learning are effectively able to predict the most suitable treatment plans

Table -2 AI-driven applications for treatment optimization and operational efficiency

Application	Website	Country of Origin	Year	Description
Treatment Optimization	www.vetoptimizer.com	USA	2022	Machine learning to analyse patient data and recommend the most effective treatment options, improving the precision and outcome of veterinary care.
Predictive Analytics for Treatment	www.predictvet.com	UK	2023	AI to predict the success rates of various treatments for specific conditions, helping veterinarians make more informed decisions.
Operational Efficiency	www.vetoperations.com	Australia	2021	AI systems automate appointment scheduling, data management, and inventory control, improving the overall efficiency of veterinary clinics.
Diagnostics Support	www.animalradiologyai.com	Germany	2022	AI-assisted imaging tools help veterinarians detect diseases like tumours, fractures, and infections with greater accuracy and speed.
Workflow Automation	www.vetworkflowai.com	USA	2021	Automates routine administrative tasks, reducing the time spent on paperwork and allowing veterinary staff to focus on patient care.
Inventory Management	www.vetinventoryai.com	Canada	2021	AI systems track inventory usage, automatically reorder supplies, and manage stock levels, ensuring efficient resource management in veterinary clinics.
Patient Monitoring	www.healthmonitorai.com	South Korea	2022	Uses AI to monitor animals' health status continuously, providing alerts for early intervention and optimizing care for hospitalized patients.
Virtual Veterinary Consultations	www.vettelemedai.com	USA	2023	AI-powered telemedicine platforms facilitate virtual consultations, using data analysis to assist in diagnosis and treatment recommendations remotely.
Vetspire	vetspire.com	USA	2018	Practice management software

Table -3 AI applications in the production animal health

Application	Website	Country of Origin	Year	Description
Predictive Analytics for Animal Health (PAH)	www.pah.ai	USA	2020	Analyses historical data to forecast disease risks.
Cowlar	www.cowlar.com	Canada	2017	A smart collar that tracks health metrics in cows.
Ceres Tag	www.cerestag.com	Australia	2019	Smart ear tag that optimizes feeding strategies.
Connecterra	www.connecterra.io	Netherlands	2016	Analyses cow behaviour to detect early health signs.
Agridigital	www.agridigital.com	Australia	2020	Uses AI for real-time health issue detection via video.
Heatime	www.heatime.com	USA	2015	Monitors oestrus to optimize artificial insemination.
PigWatch	www.pigwatch.com	Denmark	2019	Monitors sows for oestrus detection and reproductive health.
Oviflex	www.oviflex.com	Australia	2020	Uses sensors to detect heat in sheep for breeding optimization
AgriWebb	www.agriwebb.com	Australia	2014	Comprehensive platform for livestock management.
Neogen	www.neogen.com	USA	2021	Offers genomic testing for improved breeding decisions.
Smartbow	www.smartbow.com	Austria	2018	Ear tag system for monitoring health and location.
Allflex	www.allflex.com	USA	2019	Provides monitoring solutions for individual animals.
Ruminant Vision	www.ruminantvision.com	USA	2020	Monitors emissions and environmental impact of farming.
HeatStress	www.heatstress.com	USA	2021	Monitors heat stress levels in cattle using AI.
Climacell	www.climacell.com	Israel	2018	Provides weather data to predict climatic impacts on livestock.
SmartFarm	www.smartfarm.com	Australia	2020	Uses AI to analyse environmental conditions affecting animal health.
CowManager	www.cowmanager.com	Netherlands	2015	Oestrus detection with sensors
Bovine AI	www.bovine-ai.com	USA	2020	Ultrasound follicle detection
Ztag	www.ztag.com.au	Australia	2017	Heat detection in pigs
SyncroMax	www.syncromax.com	USA	2016	Predictive analytics for breeding
Fertility Focus	www.fertilityfocus.co.uk	UK	2021	Oestrus detection app

for individual animals. This eventually enhances the precision of diagnoses and the efficacy of therapeutic approaches (Basran and Appleby, 2024). A very useful program for the practitioner is "Vetspire", an AI based practice management software released in 2018 from the USA, that streamlines clinic operations, improving efficiency and patient care (Ouyang *et al*., 2021). Collectively, these examples are readily available and can make a huge transformative impact on machine learning in veterinary medicine, benefiting the QOL of patients and easing the workflow and productivity of veterinary practices (Zhang *et al*., 2024). A table summarizing various AI-driven applications for treatment optimization and operational efficiency in veterinary practice setups is given below.

AI applications in Production Animal Health

Artificial Intelligence (AI) has revolutionized the pivotal aspect of animal husbandry and health (Fuentes *et al*., 2022) . AI-driven predictive monitoring technologies augment animal health and productivity through early disease prediction, early heat detection for reproductive efficiency, preventive health management, improving productivity by enhanced animal welfare, and boosting economic efficiency in livestock and poultry farming practices (Bao and Xie, 2022). For instance, an AI-driven disease-monitoring application "Predictive Analytics for Animal Health (PAH)" helps farmers be prepared for health risks based on the inputs from historical data. Another interesting advancement is AI integration in animal behaviour assessment by detecting real-time health parameters, motion sensors, and face mapping (Congdon *et al*., 2022). Wearable technologies like "Cowlar" are highly popular in organised cattle farms in USA. The most sought AI application among large-scale farmers is AI-driven heat detection systems in bovines, ovine, and swine for optimized animal breeding resulting in enhanced reproduction efficiency of livestock (Sharifuzzaman *et al*., 2024).

The "CowManager", is a highly popular ML-based application from the Netherlands developed in 2015, that employs sensors to detect heat in cows that aids in timely artificial insemination (Reynolds *et al*., 2019). Based on the success of this, "Bovine AI", another program developed in the USA in 2020, identifies ovarian follicles by ultrasound image analysis aiding successful interventions in bovine reproduction. Meanwhile, "Ztag", an AI-based sow behaviour detection application program from Australia launched in 2017, ensures a high success rate in swine reproduction. The application "Fertility

Focus" from the UK, developed in 2021, assists in oestrus detection in sheep and goats. Other examples of widely used AI applications for heat detection are "Heatime", "Oviflex", and" Pigwatch". AI applications also aid in assessing animal behaviour and welfare (Debauche *et al*., 2021). AI applications are also widely popular in animal nutrition to assist in preparing optimized feed formulations (Trotter, 2019).

Real-time monitoring and tracking of livestock movements can be achieved by machine learning applications (Mulrooney and Harkness, 2023). An application named "Ceres Tag" is an example for such application where solar-powered direct-to-satellite GPS technology helps farmers to track individual animals and their movements without using cellular networks. This application can also detect livestock theft by sending alerts (Hofmann, 2024). AI technologies are also used for monitoring climatic change and its impact on animal stress and productivity (Sejian *et al*., 2022). AI-integrated applications like "ClimaCell" and "HeatStress" use wearable bio sensors to assess physiological responses to climatic stress. Additionally, these applications supports weather data services for managing climatic impacts on livestock. Another advancement in AI-integrated comprehensive farm management systems is the development of applications like "AgriWebb" to augment decision-making and enhance operational efficiency by machine learning outputs. These applications integrate a wide range of farm operations enhancing profitability and sustainability (Micle *et al*., 2021). The following table provides a quick summary of key AI applications in the production animal health.

AI Applications in One Health

AI potentiates the interdependence of human, animal, and environmental health One Health approaches by augmenting efficient surveillance, early detection, and predictive modelling of health risks of zoonotic diseases (Wahl *et al*., 2018) . The collaboration between sectors facilitated by AI facilitates aiding timely implementation of preventive measures enhancing the management of public health (Amer and Amer, 2024). Large datasets such as clinical, ecological, and environmental data from diverse sources are processed by predictive modelling to identify patterns that enable accurate forecasts about zoonotic outbreaks, disease transmission, and environmental changes that ultimately affect public health (Becker *et al*., 2022). The table below illustrates the AI applications in zoonotic disease detection and One Health

Table-4: AI Applications in zoonotic disease detection and one health

Application	Website	Country of Origin	Year	Description
Zoonotic Disease Detection	www.zoonoticdiseaseai.com	USA	2023	Uses machine learning to predict and detect zoonotic diseases by analysing data from human, animal, and environmental sources to mitigate the spread of outbreaks.
Environmental Health Monitoring	www.environmentalhealthai.com	UK	2022	Leverages AI to analyse environmental data and identify patterns that could lead to health risks for humans and animals, helping to prevent ecosystem disruptions.
Predictive Modeling for Epidemics	www.predictivehealthai.com	USA	2022	AI tools analyse global health and environmental data to forecast outbreaks of diseases like Ebola and COVID-19, aiding in early intervention strategies.
Wildlife and Livestock Health	www.wildlifelivestockai.com	Australia	2021	AI technologies track animal health in both wildlife and farm settings, identifying potential threats from diseases like avian influenza and African swine fever.
One Health Surveillance Systems	www.onehealthai.com	Global	2023	AI-powered platforms integrate human, animal, and environmental health data to provide a comprehensive view of public health, enabling faster response to crises.
Ecosystem and Biodiversity Monitoring	www.ecosystemhealthai.com	Canada	2021	Analyses biodiversity and ecosystem data to predict how environmental changes might impact public and animal health, supporting sustainable conservation efforts.
Data Integration for Health Policy	www.healthpolicyai.com	Global	2023	Combines data from human health, animal health, and environmental factors to support evidence-based policy decisions for public health management.
Early Warning Systems for Emerging Diseases	www.diseasewarningsystem.ai	South Africa	2022	AI systems analyse environmental and population health data to predict where zoonotic diseases are likely to emerge, allowing for early warnings and targeted responses.
Companion Animal Health	companionanimalhealth.com	USA	2019	Predictive analytics for outbreaks

Artificial Intelligence (AI) in sports medicine and the care of working animals

The use of Artificial AI detection is transforming the way veterinarians approach hoof care and management of equestrian animals and working canines by optimizing approaches for injury prevention and improving performance (Feuser *et al*., 2022). Integrating AI in wearable sensors assesses biomechanics of foot movement patterns facilitating early detection of lameness and optimizing training protocols. AI-enabled motion tracking system incorporating the American Association of Equine Practitioners (AAEP) grading scale has become popular among equine practitioners and in training horses. (Feuser *et al*., 2022). Smartphone applications using computer vision algorithms compare head and pelvis motion measurements to those from a multi-camera system that employs reflective markers placed on the skin. AI applications that utilise computer vision algorithms like the Equine Lameness Detection System (ELDS) and pressure mapping systems like "HoofView" provide real-time feedback on the equine limb and body movement, and also detect the distribution of hoof pressure. AI-enabled biometric tracking systems can detect early injuries, facilitate rehabilitation, and reduce recovery times (Amirhosseini *et al*., 2024).

An overview of various AI software platforms and tools for performance optimization in equines and working animals is given below.

Applications of AI in Wildlife and Exotic Animal Health Management

Applications of AI are increasingly being used in wildlife and exotic animal health. These are mainly used for, health monitoring, population tracking, and aiding conservation efforts. AI helps in the rapid intervention of wildlife conservation efforts by AI-driven camera traps, unmanned ariel vehicles, and smartphone applications (Gonzalez *et al*., 2016). Patterns of animal behaviour, animal movement, and habitat are closely monitored by AI applications that serve for conservation planning(Rast *et al*., 2020). Additionally, some AI applications facilitate in genomic monitoring of endangered species augmenting breeding programs for enhancing wildlife conservation strategies. The most popular AI applications in Wildlife and Exotic Animal Health Management are listed below

Challenges and limitations of AI applications in veterinary practice

The transformative capacity of AI offers higher efficiency in all interventions in veterinary medicine. Several challenges and limitations are identified despite these

Table -5: AI Applications for performance optimization in athletic and working animals

Application	Website	Country of Origin	Year	Description
Performance Optimization	www.animalytics.com	USA	2022	Uses wearable sensors with AI to track movement patterns, joint angles, and stride lengths, enhancing training effectiveness and identifying early injury risks.
Injury Prediction	www.vetai.org	USA	2021	Develops machine learning models that analyse health data to predict injury risks, specifically targeting musculoskeletal issues in equine and military dogs.
Rehabilitation and Recovery	www.agrotech.com	Netherlands	2020	Provides AI-driven platforms to monitor recovery progress and adapt exercise plans for army and service dogs based on real-time data and individual responses.
Injury Prevention and Monitoring	www.smartvetsports.com	UK	2021	Offers AI tools to track performance indicators in equine athletes and military dogs, alerting handlers to early signs of strain or overexertion.
Biometric Analysis	www.petbiometech.com	Germany	2022	Combines AI with biometric tracking to optimize performance and monitor health in canine and equine sports, aiding in the early detection of overuse injuries.
Lameness Detection	www.elds.org	USA	2021	Uses motion capture technology to detect early signs of lameness by analysing changes in gait, providing more accurate diagnosis and intervention.
Pressure Mapping	www.hoofview.com	Global	2021	Provides real-time feedback on pressure distribution across a horse's hooves to detect areas of increased strain, helping identify lameness.
Lameness Detection via AI	www.soundnesssolutions.com	USA	2022	Uses AI and image recognition to analyse video footage of horses and detect subtle signs of lameness, providing objective and reliable data.

Table-6: AI Applications in Wildlife and Exotic Animal Health Management

Application	Website	Country of Origin	Year	Description
Wildlife Health Monitoring	www.wildtechai.com	USA	2022	AI aided image recognition to monitor wildlife populations, detect diseases, and track animal movement in remote areas.
Population Tracking	www.animaltracker.com	Australia	2021	AI enabled GPS and satellite data systems to track animal movement and populations.
Conservation Efforts	www.ecosystemai.com	UK	2022	AI models analyse environmental data to assist in habitat restoration projects, improving biodiversity conservation efforts.
Genetic Monitoring	www.genomicwildlife.com	USA	2021	AI to analyse genomic data from wildlife populations, enhancing breeding programs and tracking genetic diversity.
Behavioral Studies	www.behaviortrack.com	Canada	2021	AI tools are used to study animal behaviour patterns, aiding in the understanding of health indicators and social structures of exotic species.
Disease Detection	www.wildlifehealthai.com	South Africa	2023	AI to detect early signs of disease in wildlife populations, helping researchers take preventive measures before outbreaks occur.

merits (Burti *et al*., 2024). The availability and quality of reliable data is identified as the primary challenge which the backbone of a productive machine-learning effort (Amer *et al*., 2024) The available data in veterinary medicine being smaller, and fragmented, limits its exploitation to the fullest potential (Basran and Appleby, 2022). Numerous veterinary clinics still follow conventional paper records or inconsistent digital formats, which limits the generation of standardized datasets for developing AI applications (Currie *et al*., 2023).

Inadequate representation of the data covering all species and breeds in varied geographical locations is a unique challenge identified in veterinary medicine (Amer *et al*., 2024). Variations in capturing equipment and quality of images in computer vision, coupled with lack of uniformity of data sets from specific niches combined with interpretation bias could considerably impact the reliability of accurate prediction by AI models (Valle *et al*., 2024; Bellamy, 2023). Because of the obscure nature of decision-making process, many deep learning models are often regarded as "black boxes" as they are difficult for humans to comprehend (Sai *et al*., 2024). AI integration in veterinary practice also raises ethical concerns, especially about patient welfare apart from data privacy and ownership of the data retrieved from database of veterinary clinics (Bellamy, 2023). The cost factor in developing and implementing an AI model poses challenges in accepting the technology by many veterinary establishments. In addition to this, training of AI models, and their timely updates and maintenance further adds to the financial burden in many small veterinary practice establishments (AlMuhaideb *et al*., 2019; Chu, 2024). The attitude and willingness of many veterinarians to adopt AI applications for routine practice also considerably affect the popularity of these applications (AlMuhaideb *et al*., 2019; Appleby and Basran, 2022; Bellamy, 2023)

SUMMARY

Transformative interventions through AI technology have revolutionized all fields of human activity and have marked the greatest revolution of the 21st century for humankind. Veterinary medicine, like any other field, has not been exempt from this transformation. AI applications have revolutionized all areas of veterinary medicine, including diagnosis, treatment, preventive health management, and predictive medicine, ultimately streamlining workflows and efficiency. Though these augmentations by AI technological innovations are highly difficult to deny, the realities of challenges and ethical considerations - such as ensuring data privacy, the credibility of available data, the cost of applications and training, interpretation challenges, and, above all, the willingness of veterinarians to adopt these novel technologies - require special attention. It is certain that at any point in time, AI may not replace veterinarians, but veterinarians who get trained and wilfully embrace AI will probably surpass those who do not. This review article aims to provide a snapshot of the available AI platforms for veterinary practitioners with a clear intention to raise awareness and promote the regular use of these applications. This could further generate data that enhances the accuracy of these applications, ultimately improving the quality of animal health.

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